AN ASSESSMENT OF THE FAILURE OF THE WADI DERNA DAMS AND LESSONS FOR ENHANCING DAM SAFETY

Laurent Mouvet
Civil Eng. EPFL-SIA
Vice President ICOLD
Past President SwissCOLD

08/04/2025

Wadi Derna Dams Failure
Libya - September 10-11, 2023

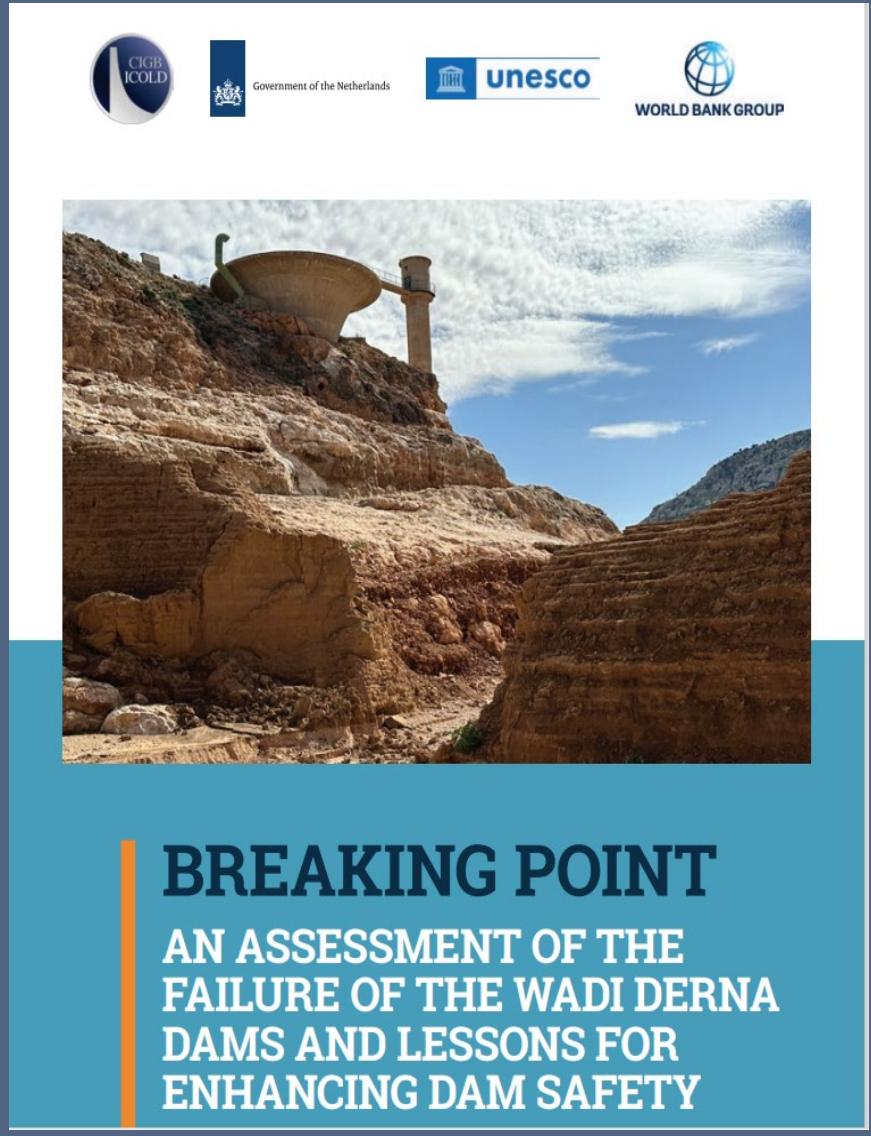
Joint Case Analysis

- ICOLD – International Commission on Large Dams
- Netherland's DRRS (Dutch Risk Reduction & Surge Programme)
- UNESCO
- WORLD BANK

Workshop with the Libyan authorities on 15-16 April

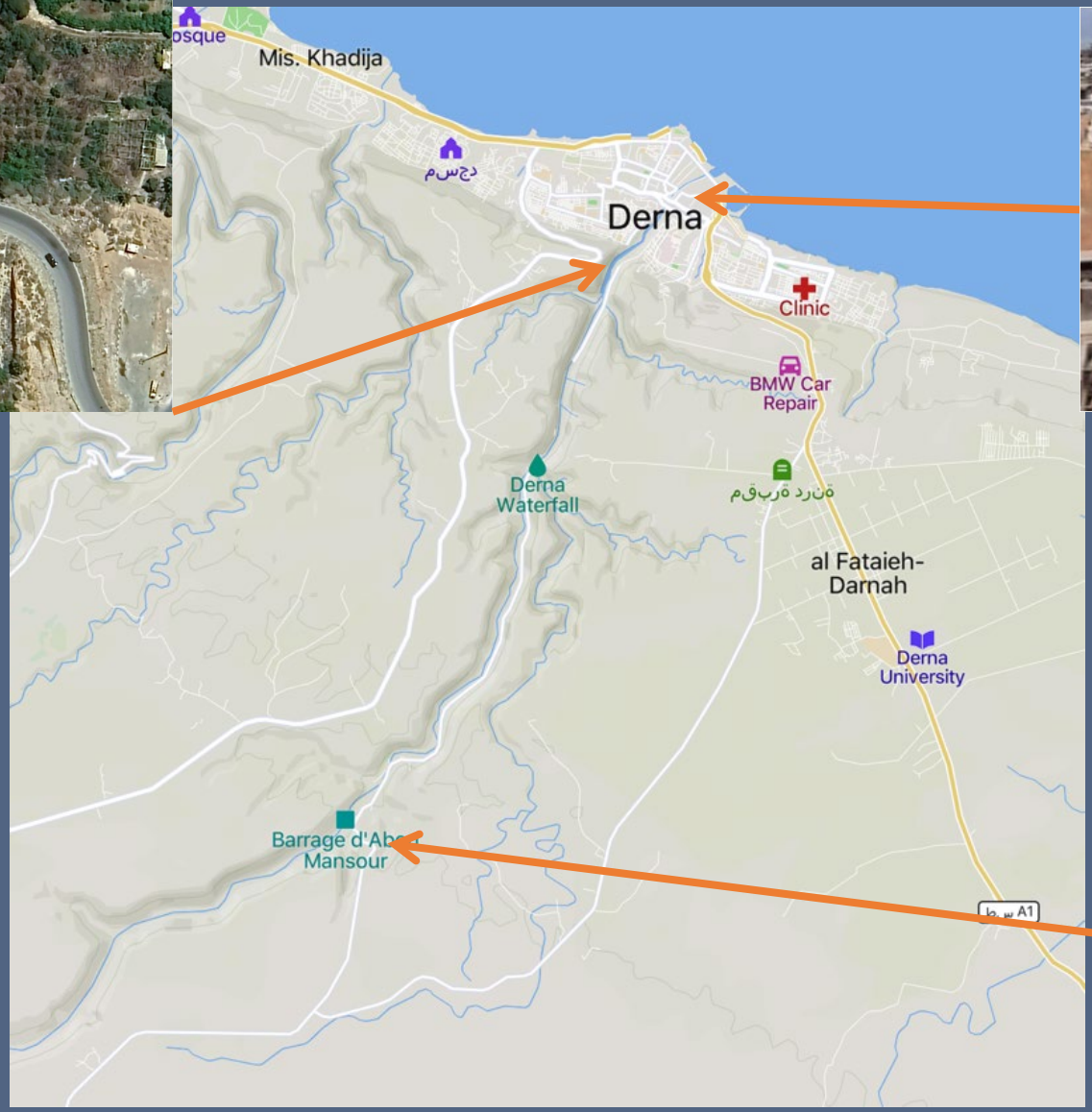
Final Report to be released very soon

A Conference edition was released for the ICOLD Annual Meeting 2024 in New Delhi (not for citation or publication)



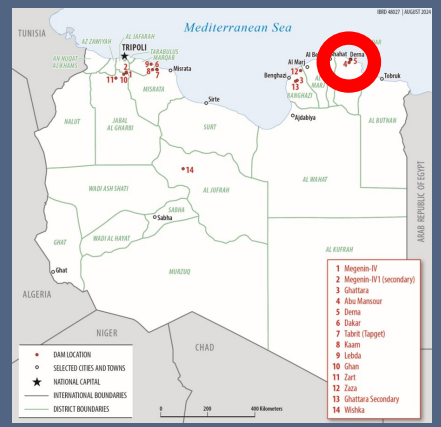
Wadi Derna Dams Failure
Libya - September 10-11, 2023

Derna Dam
H_{max} 40m (26m)
Vol 1.2 Mm^3



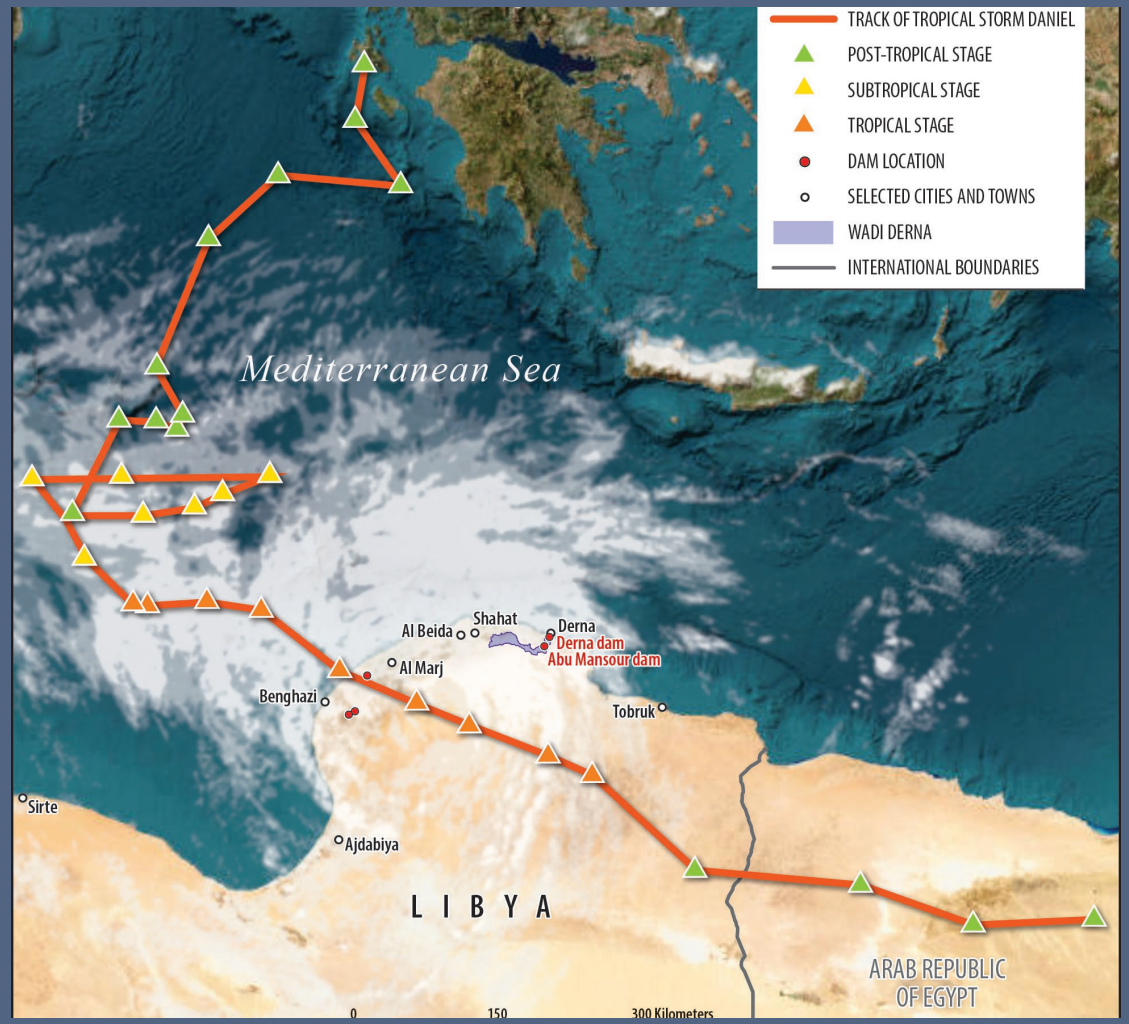
City of Derna before the disaster

Abu Mansur dam
H_{max} 73m (48m)
Vol 23.7 Mm^3



3

Wadi Derna Dams Failure
Libya - September 10-11, 2023



Storm Daniel

- Made landfall in Libya around September 9th
  - Storm Daniel's west-east path is the worst-case scenario for the accumulation of runoff in Wadi Derna, resulting in high rainfall quantities with an intensity that were much larger than the infiltration capacity.

- Rainfall event of circa 150-300 mm
  - 414 mm rainfall reported by National Meteorological Agency
  - Satellite-based precipitation measurements show consistently lower rainfall intensity
  - Optical satellite imagery was also used to identify several waterbodies that filled during the storm event and identify precipitation levels between 120-200 mm.
  - The return period of the event is estimated between 500 and 1000 years

Magnitude of the flood

- The design flow for the dams was based on a rainfall event with a return period of 1000 years.
- The estimates of the return period associated with the peak flow and flood volume of the event are **considerably higher** than the original design estimates.

  - The 2 dams were dramatically under-designed from the hydrological point of view
  - Spillway capacity and reservoir volume out of proportion compared to the Sept. 2023 flood

Hydraulic design criteria related to flood protection for Derna and Abu Mansur Dams

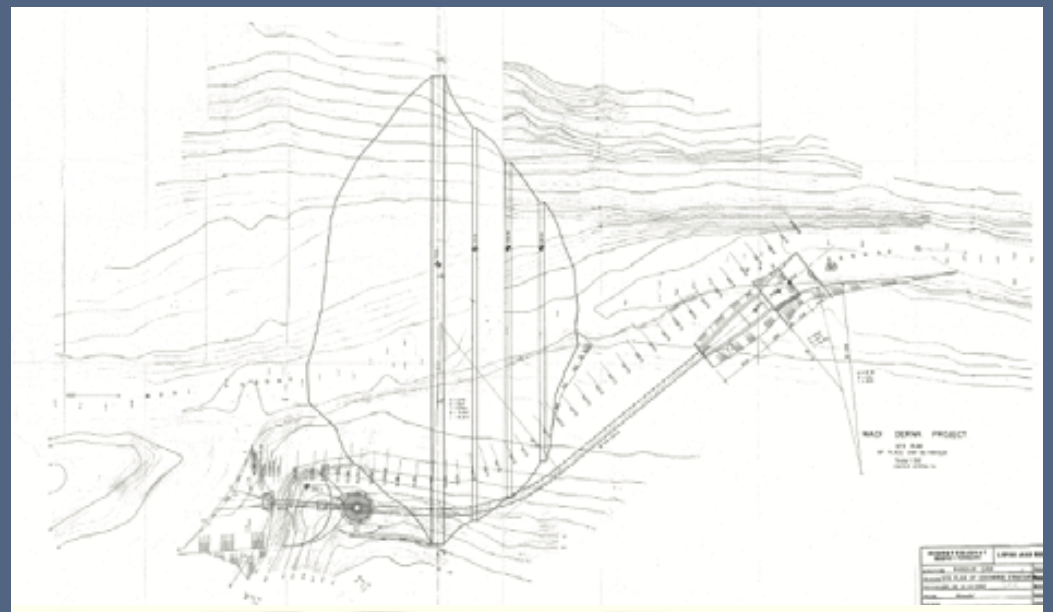
Dam	Derna			Abu Mansur		
	Original design (1972)	Stucky Review (2003)	Model Estimates (2023)	Original design (1972)	Stucky Review (2003)	Model Estimates (2023)
Return period (year)	1,000	1,000	1,000	1,000	1,000	1,000
Peak flow (m^3/s)	~350	906	1,750	840	1,360	1,950
Flood volume (Mm^3)	4	35.4	61	14	47.6	78
Maximum released flow (m^3/s)	350	570		170	420	

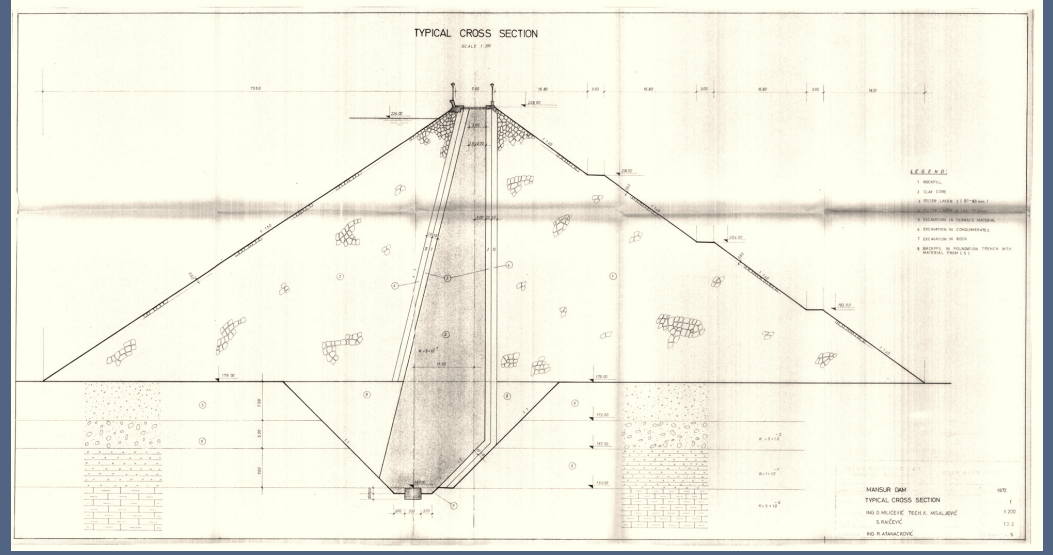
Vol reservoir 1.2 Mm^3

Vol reservoir 23.7 Mm^3

Abu Mansur Dam

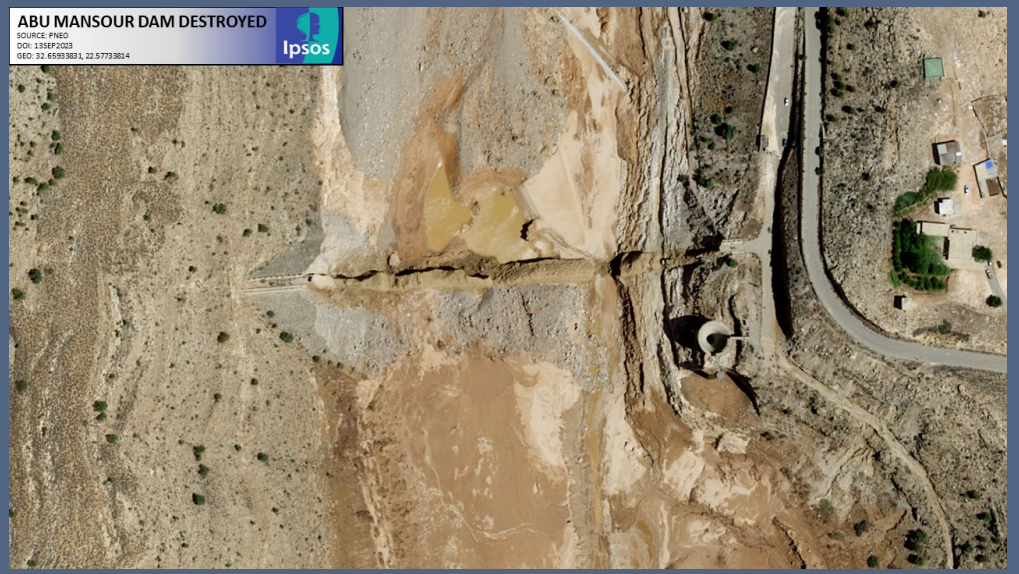
- Embankment dam with a thin clay core
- Located ~11 km upstream of Derna Dam
- Catchment area = 476 km^2
- Height = 73 m from the foundation
- Storage Volume = 23.7 MCM
- Morning-glory type overflow spillway
- Spillway capacity = 170 m^3/s





Abu Mansur Dam

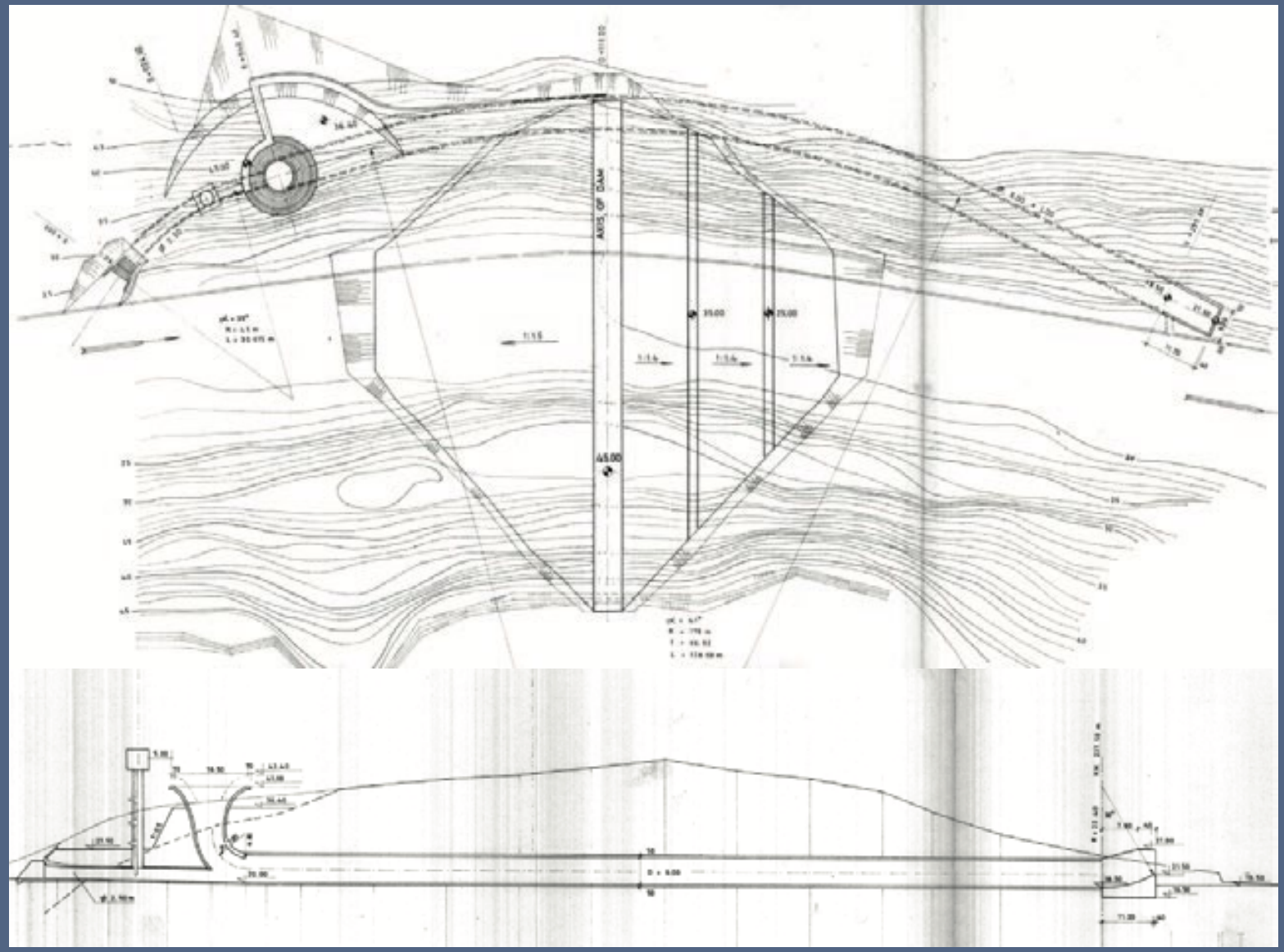
- Embankment dam with a thin clay core
- Located ~11 km upstream of Derna Dam
- Catchment area = 476 km^2
- Height = 73 m from the foundation
- Storage Volume = 23.7 MCM
- Morning-glory type overflow spillway
- Spillway capacity = 170 m^3/s



Wadi Derna Dams Failure
Libya - September 10-11, 2023

Derna Dam

- Embankment dam with a thin clay core
- Located ~1 km upstream of Derna city
- Catchment area = 575 km^2
- Height = 40 m from the foundation
- Storage Volume = 1.15 MCM
- Morning-glory type overflow spillway
- Spillway capacity = 350 m^3/s



Derna Dam

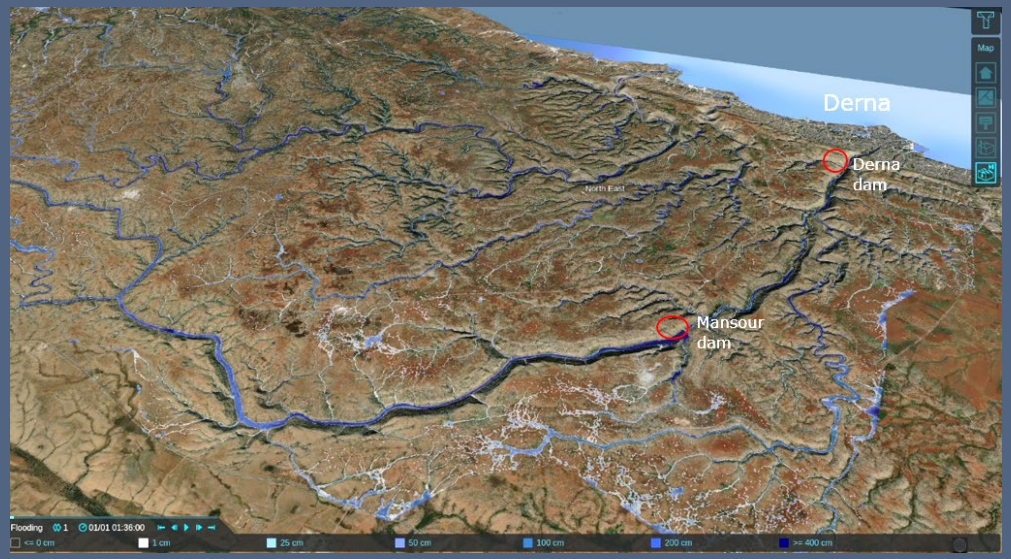
- Embankment dam with a thin clay core
- Located ~1 km upstream of Derna city
- Catchment area = 575 km^2
- Height = 40 m from the foundation
- Storage Volume = 1.15 MCM
- Morning-glory type overflow spillway
- Spillway capacity = 350 m^3/s

Storm Daniel – Damage Estimates

- Damages and losses assessed at US$1.65b, equivalent to 3.6% of Libya's GDP
- More than 250,000 people were affected, with fatalities exceeding 13,000 people, more than 8,000 people unaccounted for and 45,000 people displaced
- More than 18,500 houses are estimated to have been destroyed or damaged, equivalent to seven percent of the country's housing stock
- Initial reconstruction estimates in excess of US$1.8b, with >70% for infrastructure, the largest component being the housing sector

Magnitude of the flood

- Storm Daniel's west-east path represents the worst-case scenario for the accumulation of runoff in Wadi Derna, resulting in high rainfall quantities with an intensity that were much larger than the infiltration capacity.
- A hydrological model was calibrated to several historic flood events of with a sensitivity analysis testing a rainfall panel ranging from 150 to 300 mm.



A Wall of Water

The flood wave resulting from the failure

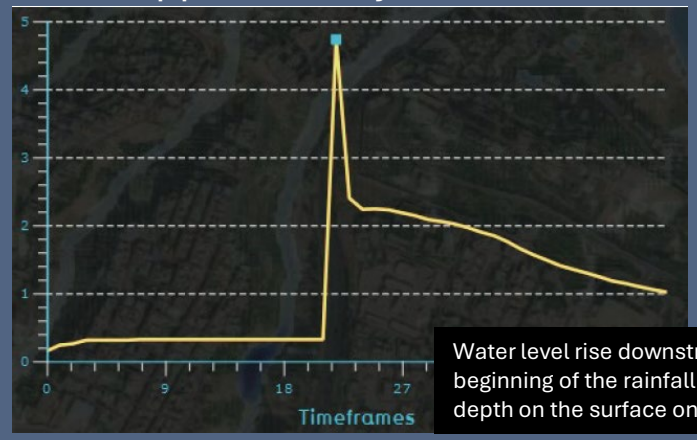
- The failure of the Derna Dam is estimated to have generated a first flood wave with a flow ranging between 1,500 and 5,000 m^3/s.
- Simulations of the second flood wave that was caused by the collapse of Abu Mansour dam suggests an estimation of discharge of around 7,000 m^3/s, significantly exceeding the capacity of the city's river channel, which could handle a maximum of around 1,000 m^3/s

The water level in Derna during the 2023 flood event.

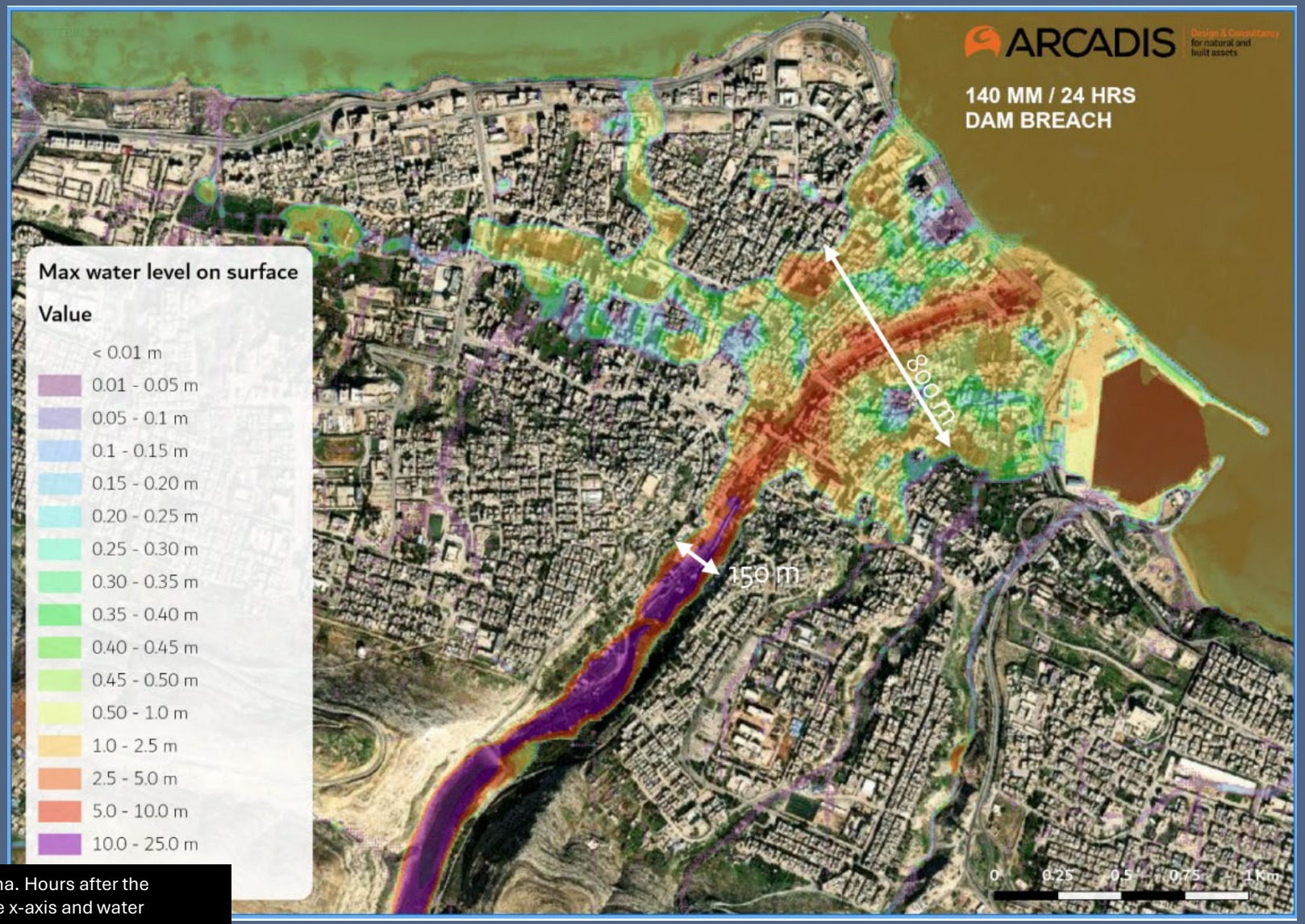
Hydrological Model

Results of the **max water level on surface** after the dam breach

- The width of the main flow channel would have extended over 800 meters (indicated by white arrow)
- Water level rise in the city of Derna between approx. 5-8 masl within 30 minutes.
- The water level drops and sinks out at about 1 meter in approximately 24 hours.

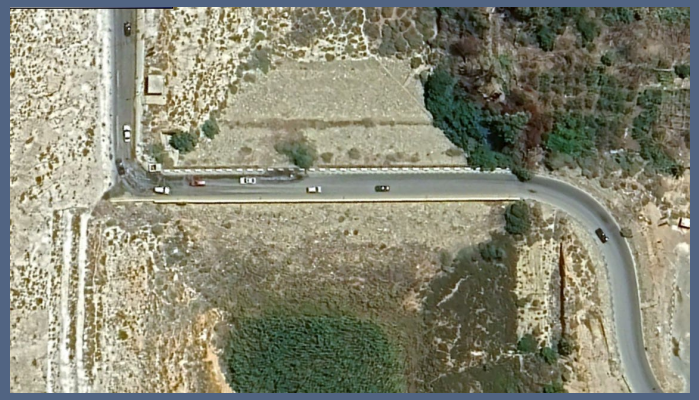


Water level rise downstream in Derna. Hours after the beginning of the rainfall event on the x-axis and water depth on the surface on the y-axis.



Chronology of dam safety reviews

Derna dam
H_{max} 40m (26m)
V=1.2 Mm^3



Abu Mansur dam
H_{max} 73m (48m)
V=23.7 Mm^3

Design 1970-74
Commissioning: 1978

Monitoring report 1984, by the contractor

- excessive settlement of both dams
- watertightness issue at the two dams
  3 m^3/s under less than 14m head at Abu Mansur,
  3 sinkholes at immediate US Derna

Libyan dam inspection, UNDP 1994

- Concern with the settlement at Abu Mansur dam crest
- Recommendation: periodic inspections

Safety assessment and rehabilitation project 2004

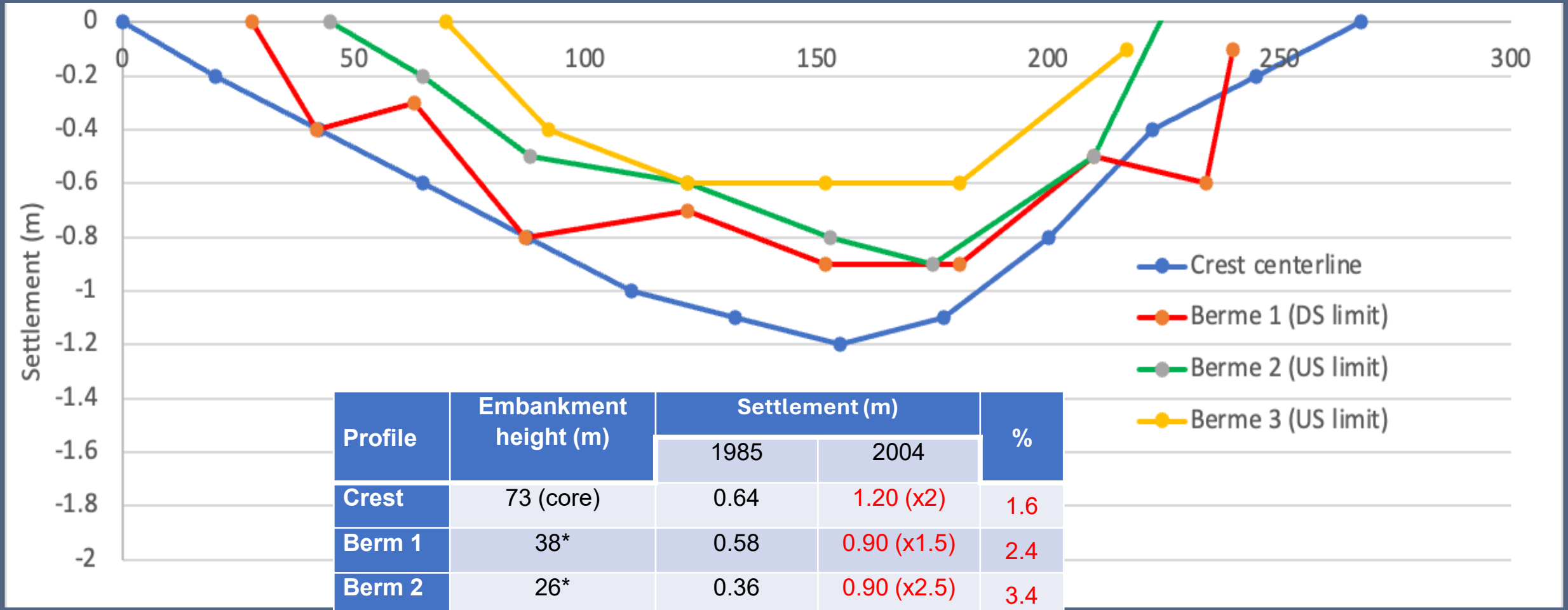
- Reassessment of the hydrology
- Design of new spillway facilities
- Improvement of water tightness
- Upgrade the monitoring system

Work never started

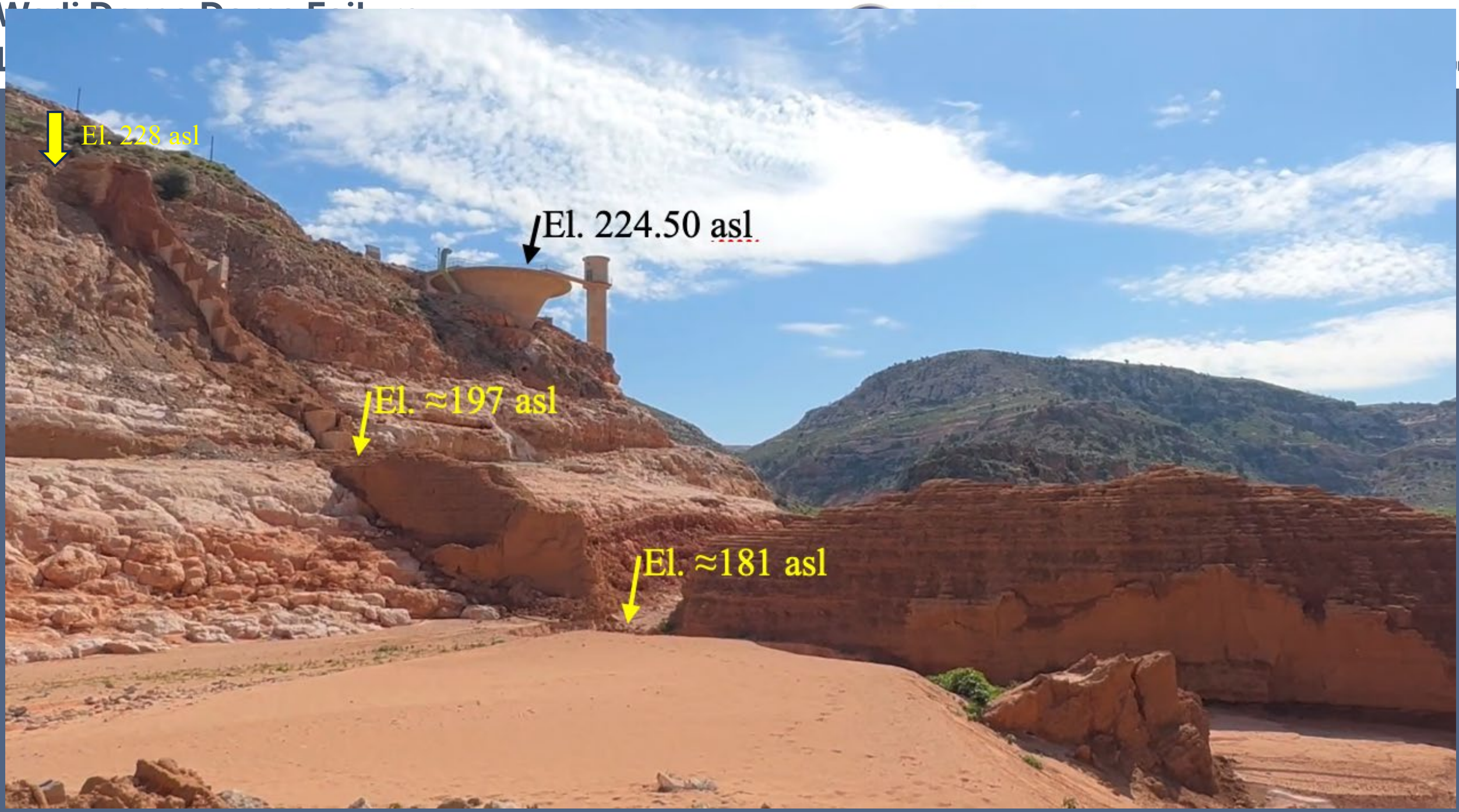
- Contract cancelled in 2010

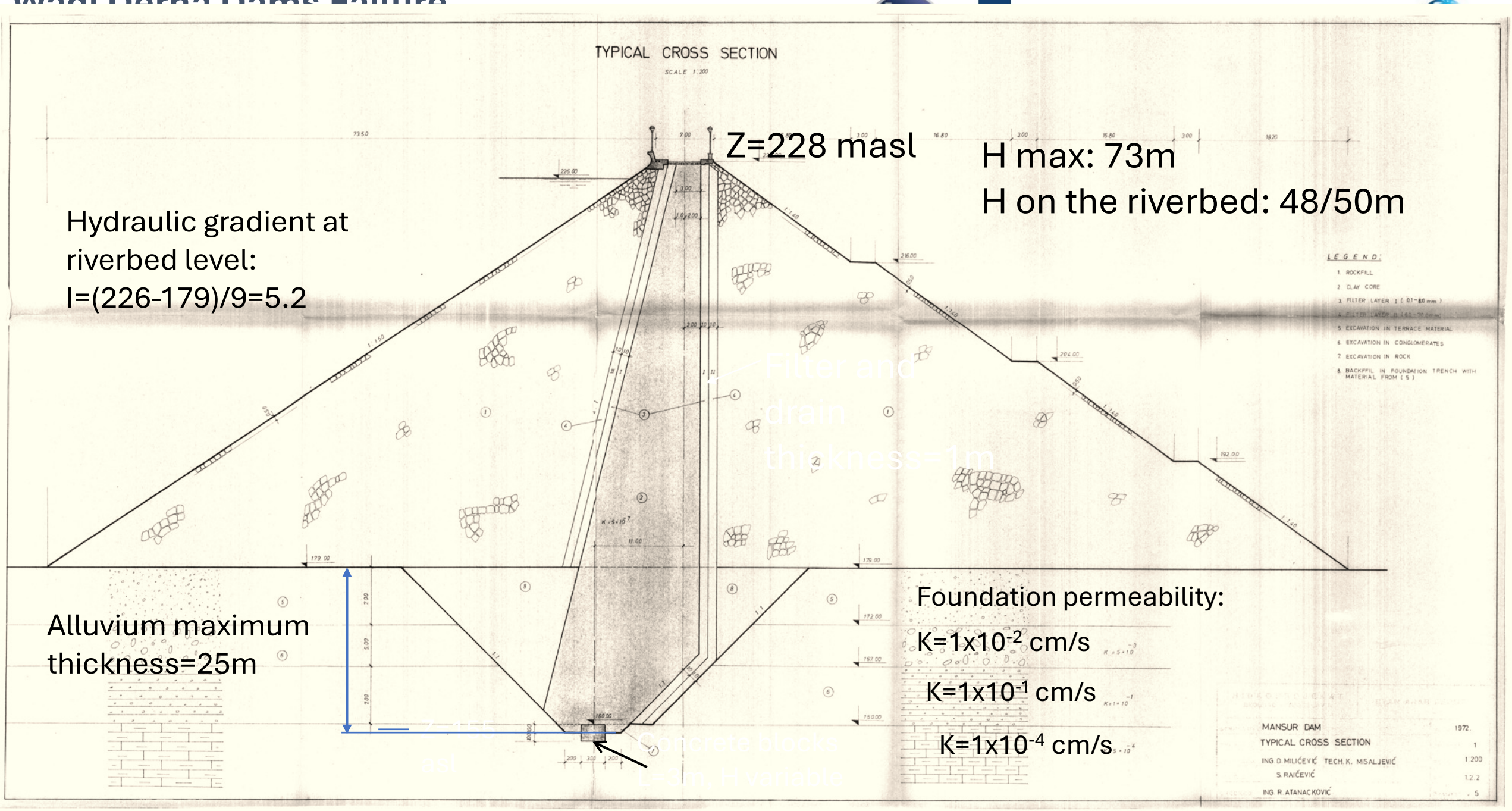
Crest Settlement – Abu Mansur Dam, 2004

Crest Settlement – Abu Mansur Dam, 2004



Profile	Embankment height (m)	Settlement (m)		%
		1985	2004	
Crest	73 (core)	0.64	1.20 (x2)	1.6
Berm 1	38*	0.58	0.90 (x1.5)	2.4
Berm 2	26*	0.36	0.90 (x2.5)	3.4
Berm 3	14*	0.12	0.60 (x5)	4.3


El. 228 asl
El. 224.50 asl
El. ≈197 asl
El. ≈181 asl


TYPICAL CROSS SECTION
SCALE 1:200
Z=228 masl
H max: 73m
H on the riverbed: 48/50m
Hydraulic gradient at riverbed level:
I=(226-179)/9=5.2
Filter and drain thickness=1m
Alluvium maximum thickness=25m
concrete blocks
Foundation permeability:
K=1x10-2 cm/s
K=1x10-1 cm/s
K=1x10-4 cm/s
LEGEND:
1. ROCKFILL
2. CLAY CORE
3. FILTER LAYER 1 (0.1 - 8.0 mm)
5. EXCAVATION IN TERRACE MATERIAL
6. EXCAVATION IN CONGLOMERATES
7. EXCAVATION IN ROCK
8. BACKFFIL IN FOUNDATION TRENCH WITH MATERIAL FROM (5)
MANSUR DAM
TYPICAL CROSS SECTION
1972
1:200
ING. D. MILIĆEVIĆ TECH. K. MISALJEVIĆ
S. RAIČEVIĆ
ING. R. ATANACKOVIĆ

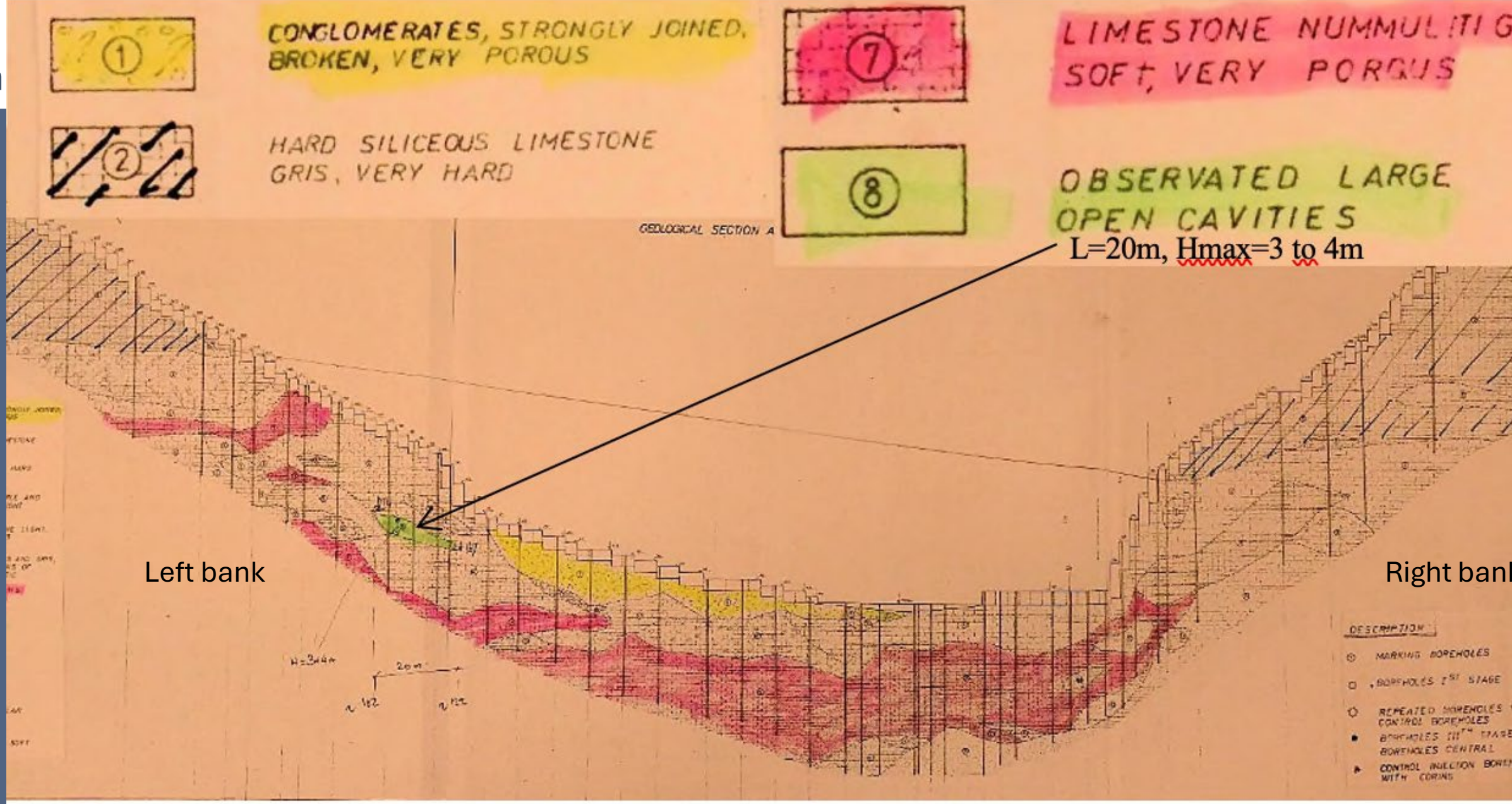


Figure 4-4: Bu Mansur dam: Geological cross section along the foundation of the core (Hidroprojekt, 1975/76)

Wadi Derna Dams Failure
Libya - September 10-11, 2023

Government of the Netherlands

unesco

WORLD BANK GROUP

Abu Mansur Dam, 2023 – Failure of the Right bank

Abu Mansur Dam, 2023
Spillway intake is intact

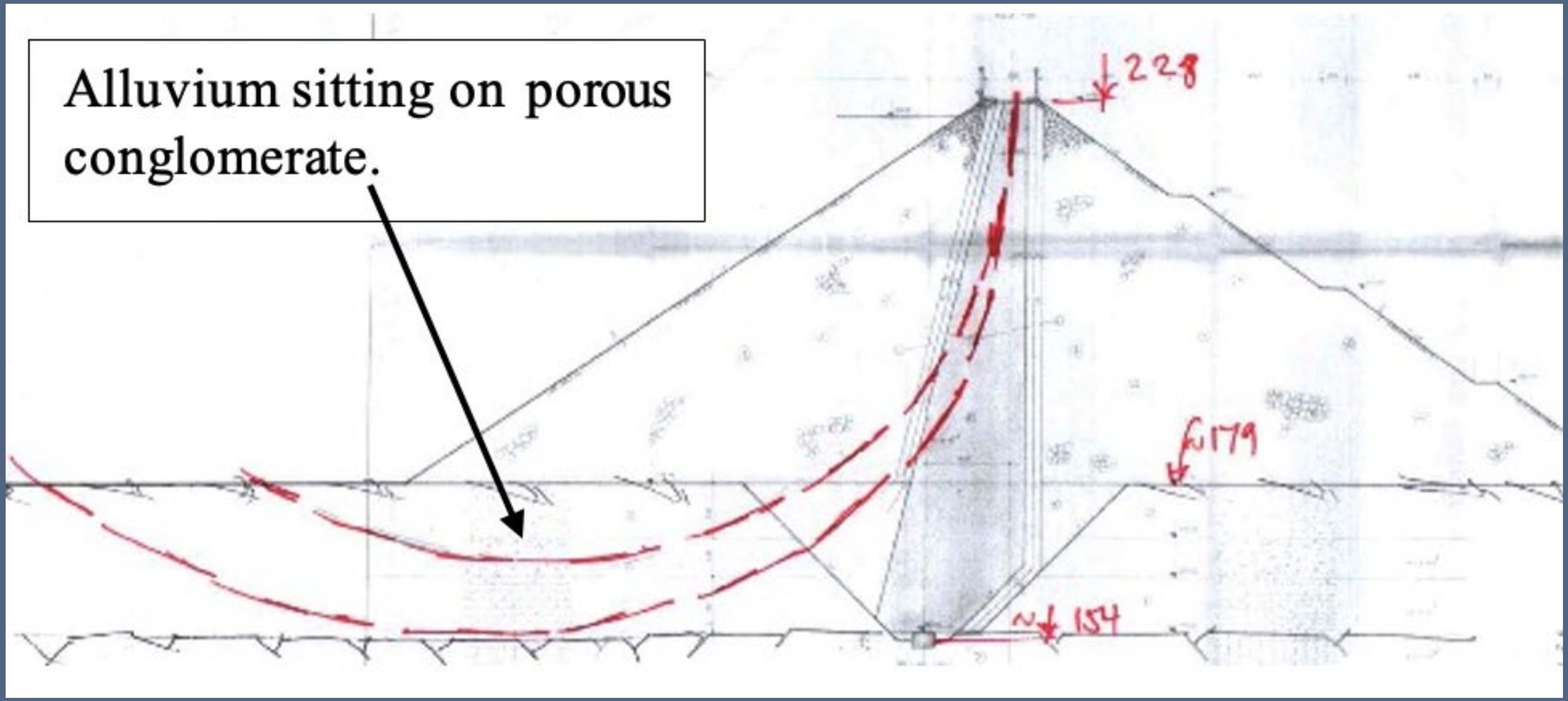
Did it spill on the 11th September 2023 ?

Abu Mansur Dam, 2023
Failure of the Left bank

What is the sliding plan on the left bank?

Wadi Derna Dams Failure
Libya - September 10-11, 2023

Wadi Derna Dams Failure
Libya - September 10-11, 2023



Wadi Derna Dams Failure
Libya - September 10-11, 2023

Wadi Derna Dams Failure
Libya - September 10-11, 2023

Lessons learned

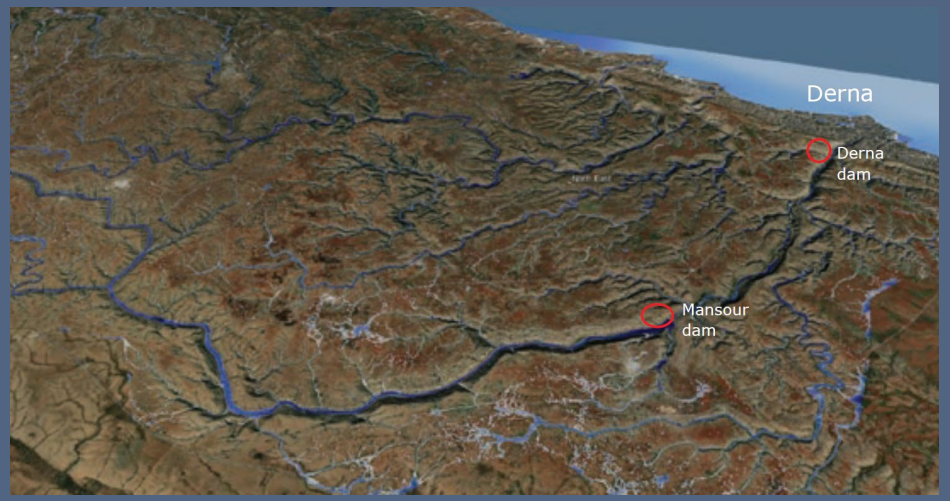
- Unclear Purpose and Protection Concept
- Design Criteria
- Periodic Safety Assessment and Surveillance
- Mitigation Measures to be implemented
- Risk Assessment and Emergency Preparedness Plan
- Flood forecasting
- Warning System

- **Inadequate Design**
- **Institutional and Organisational failure**

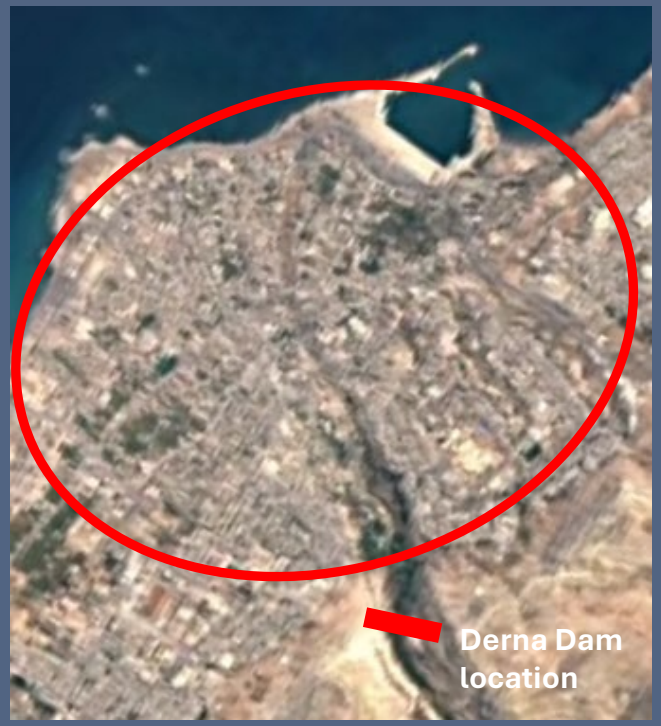
Purpose and Protection concept

According to the design documentation

- Flood protection for the city of Derna
- Aquifer recharge
- Fataya Agriculture Project



Derna City Extension in 1943



Derna City Extension in 2022

Design Criteria

Project specifications

Type of dam

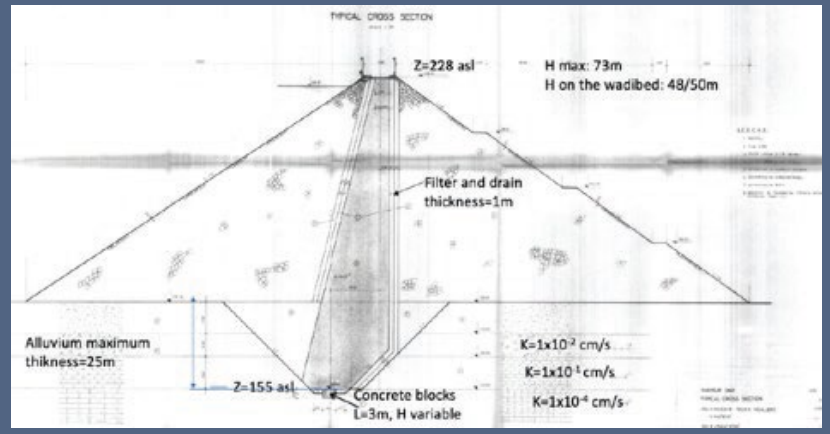
- Earthfill embankment with clay core

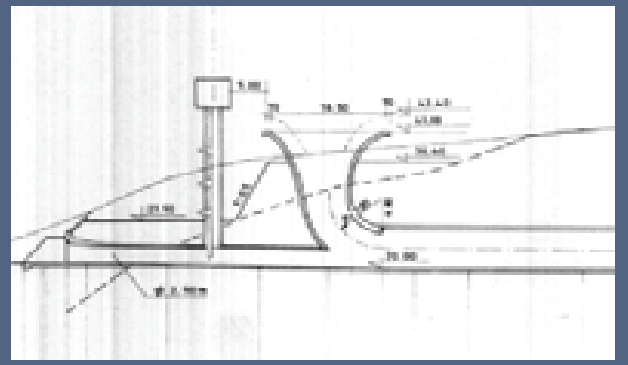
Type of Spillway

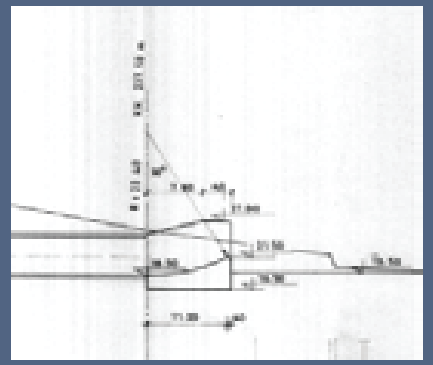
- Morning glory spillways

Is the Project resilient ?

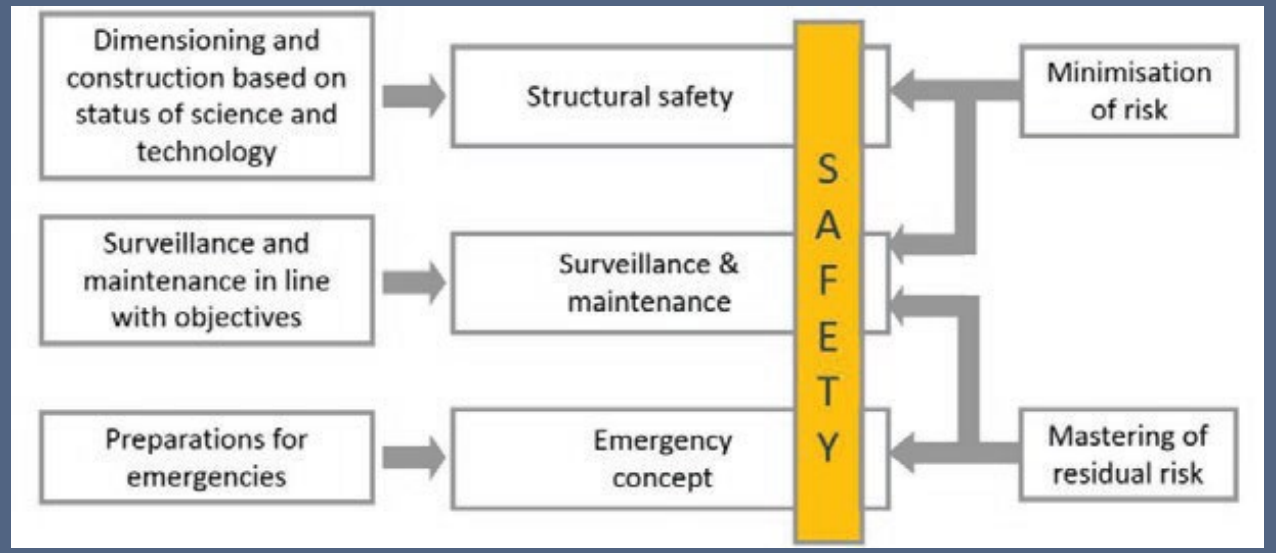
- ➢ Limited knowledge of the hydrology of the watershed at the design phase
- ➢ Level of Protection not clearly defined
- ➢ Reservoir is empty most of the time
- ➢ Rapid fillings
- ➢ No possibility of dam monitoring during the fillings
- ➢ Limited control of seepage
- ➢ High uncertainties in the assessment of the flood volume and peak discharge
- ➢ Free flow spillway
- ➢ Limited capacity







Safety Assessment and Surveillance



- **Structural Safety**
  - X Design as per standards and practice
  - ? Construction according to specifications
  - X Periodic review of safety conditions (5-10 years):
    - *Better knowledge of local conditions*
    - *Better knowledge of the dam behavior*
    - *Progress of science and practice*
    - *Change in regulations and social expectations*
- **Surveillance and Maintenance**
  - X *Maintain the dam in the condition it was designed for*
  - X *Maintain the dam safety outlets in operational conditions, tests*
  - ? *Confirm that the dam is behaving as expected during the design phase*
  - ? *Identify abnormal behavior*
- **Emergency Concept**
  - X *Prepare the protection of population, goods, and infrastructures in case of unexpected release of water*
  - X *Develop a flood forecasting system*
  - X *Install warning systems if necessary*
  - X *Define and train the emergency warning system and communication chain*

→ Predictable accident with major damages

Post-Disaster Actions

DEFINE NATIONAL AND SUB-NATIONAL PRIORITIES

1. Carry out a more detailed assessment of the 2023 flood event
2. Carry out a more detailed assessment of the dam failures
3. Improve flood forecasting, early warning systems and emergency preparedness
4. Take into account the climate change impact on flood prediction
5. Determine *the level of protection for the city of Derna*
6. Determine appropriate interventions for building back better
7. Develop a regulatory framework for dam safety assurance
8. Launch a national dam safety program
9. Implement a stakeholder engagement and communication plan

Thank you for attention

08/04/2025

Laurent Mouvet
Civil Eng. EPFL-SIA
Vice President ICOLD
Past President SwissCOLD

- https://kdrive.infomaniak.com/app/share/595022/185ad19a-2e6d-4440-bad3-8bc239737763